

Gymnolaemate Bryozoans in Fresh and Brackish Water of South Korea: Occurrence, Taxonomical Remarks and Zoogeographical Implications

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ABSTRACT

The present census on freshwater bryozoans in the Han River, Geum River and in lentic water bodies in Gangwon Province revealed three gymnolaemate species. Two of them—*Hislopia prolixa* Hirose and Mawatari, 2011 and *Victorella pavidia* Saville Kent, 1870 were recorded for the first time from South Korea. *Paludicella articulata* (Ehrenberg, 1831), on the other hand, had already been documented from a few sites since 1941. The bryozoans, all belonging to the order of Ctenostomata, were found on a variety of substrates in freshwater (*H. prolixa* and *P. articulata*) and brackish habitats (*V. pavidia*). *Hislopia prolixa* had recently been established as a new species and this is the first record for an occurrence outside of Japan, where it had been newly described from Lake Biwa and nearby satellite lakes.

Keywords: freshwater bryozoans, brackish environments, Ctenostomata, occurrence, zoogeography, South Korea

INTRODUCTION

Freshwater bryozoans comprise a small but important group within the benthic community in stagnant as well as running bodied of water. However, they are often inconspicuous and easily overlooked, despite being very common. While the total number of extant bryozoans is 6,328 species, among them, 116 species are only recorded in freshwater or brackish environments. Most of these belong to the class of Phylactolaemata, which exclusively occurs in freshwater and only 21 species are assigned to the predominantly marine class of Gymnolaemata (Bock, 2016). All 21 species are assigned to the order of Ctenostomata (Ctenostomatida) belongs to the class Gymnolaemata. Ctenostomates have no calcified zoecia and the zooids are tubular or flattened. Characteristically the zooids possess a collar-like membrane around the base of the everted lophophore which is pleated vertically and closes together when the polypide is retracted

(Annandale, 1911). In comparison to most of the phylactolaemates, tentacles are short, fewer in number and always arranged in a circle. Polymorphism of zooids, which is a characteristic of gymnolaemate bryozoans, is sparsely developed in this order and only stoloniform kenozooids occur widely throughout the Ctenostomata (Hayward, 1985).

Another characteristic feature is the development of hibernaculae, specialized resisting bodies to withstand unfavorable conditions such as low temperatures or the desiccation of their environments. Hibernaculae are only formed by ctenostomate species, as Phylactolaemata produce a variety of statoblasts (floatoblasts, sessoblasts, and ptioblasts) which represent different resting buds characteristically produced within the zooids. Hibernaculae, on the contrary, develop externally and resemble stolons or simple ordinary zooids in which the wall thickens. They are filled with a yolk-like material and often attached flat to the substrate. Jebram (1975) indicates the occurrence of hibernaculae in several marine

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ctenostomate species as well.

Bryozoa are classically determined by characters of the “hard parts” of the colonies. As there are only uncalcified zooids in the Ctenostomata, the “soft parts” including the anatomy of the polypids have to be used for species identification (d’Hondt, 1983).

Studies on freshwater bryozoans have been carried out predominately in temperate zones in Europe, North America and Japan and much less in other parts of the world such as in Southeast Asia. During the last decade a few studies mostly in tropical South East Asia, have been conducted (Wood et al., 2006, 2010; Hirose and Mawatari, 2007, 2011; Wöss and Zagorsek, 2010; Swami et al., 2014). In Korea two studies have been published: Toriumi (1941) and Seo (1998) revealed a total of 11 freshwater bryozoan species with *Paludicella articulata* as the only gymnolaemate taxon. This study will focus on the occurrence of ctenostomate Gymnolaemata occurring in non-marine environments and will present the results of the sampling years 2015–2016 accompanied by taxonomical discussions.

MATERIALS AND METHODS

Study area

South Korea is characterized by four river systems: Han, Nakdong, Geum, and Yongsan rivers. Sampling took place in all of these catchment areas and additionally in Gangwon-do in the north-eastern part of the country. Fig. 1 displays the sites in regard to results for gymnolaemate bryozoans findings, including the sites recorded by Toriumi in 1941. The sites of 2015–2016 are situated either on the bank of rivers, such as close to the weir of the Korean K-water Management Initiative or in lentic waterbodies such as reservoirs and wetlands.

The Geum River has a length of 402 km and is situated in the western territory where it flows into the Yellow Sea. It covers a catchment area of 9,912.15 km². Here a total of 3 sites were chosen, G1 and G3 represent sites in reservoirs used for recreation (e.g., fishing, tourism). G2 is situated in free-flowing parts of the river.

The Han River, situated in the north-west, is a major river of 494 km length and is widely influenced by hydroelectric power plants. Its catchment area of 35,770 km² covers about 1/6 of the entire peninsula and empties in the Yellow Sea. The sites H1 is located within the riverbanks close to weirs.

Both sites in Gangwon Province in the north-eastern part of the country are wetlands of more stagnant character. K1 is a brackish waterbody influenced by the nearby ocean, K2 is a pond-like waterbody situated in a marshland.



Fig. 1. A map with 6 sampling sites G1, G2, G3, H1, K1, and K2, collection period 2015–2016. Two sampling sites B and T by Toriumi, 1941.

Collecting and observation of specimens

Colonies were sampled by wading on the shore and collecting possible substrates such as branches, twigs, submerged water plants, stones and rocks as well as any anthropogenously introduced materials such as plastics of any kind, tires used as boat fenders and pontoons. The equipment used was a rake for lifting submerged objects, scissors, a hand saw and a knife. The goal was to cut the substrates for transport and to avoid removing the colonies from the surface they had colonized. Specimens were kept alive by transporting them to the lab in cooling bags filled with water from the actual location. Environmental data such as temperature, conductivity, salinity, dissolved oxygen and pH were measured with the help of a YSI 566 MPS instrument at the sites in Gangwon Province while at other sites (Han River and the reservoir of the Geum River) only temperature was recorded.

Specimens were identified *in vivo* using a stereomicroscope

Table 1. Collecting data of gymnolaemate bryozoans in 2015–2016: localities, species found and substrates

No.	Site			Date	Sampling	
	Code	Name	GPS		Species	Substrate
1	H1	Yeoju Weir River	37°19'31.3"N 127°36'25.3"E	3 Aug 2016	<i>Paludicella articulata</i> <i>Hislopia proluxa</i>	Branches Rock
2	G1	Chopung Reservoir	36°49'15.5"N 127°31'22.4"E	2 Aug 2016	<i>Hislopia proluxa</i>	Plastic
3	G2	Mihocheon River	36°49'36.2"N 127°29'37.0"E	14 Aug 2016	<i>Hislopia proluxa</i>	Rock
4	G3	Andeok Reservoir	35°41'01.4"N 127°05'42.6"E	29 May 2015	<i>Paludicella articulata</i>	Rope
5	K1	Hyangho Wetland	37°54'45.9"N 128°48'42.2"E	17 Aug 2016	<i>Victorella pavid</i>	Branches
6	K2	Sunfo Wetland	37°49'14.1"N 128°53'12.3"E	18 Aug 2016	<i>Victorella pavid</i>	Branches

(Model SZX 16; Olympus, Tokyo, Japan), with a magnification range of 0.7–11.5 × (zoom ratio: [0.7 × –11.5 ×], eyepiece: 10 ×, objective lens: 1 ×, magnification indication: 0.7/0.8/1/1.25/1.6/2/2.5/3.2/4/5/6.3/8/10/11.5) and an integrated camera. Afterwards they were stored in 95% or 99% ethanol. Measurements of zooids were made when specimens were alive with the help of the software microscope digital camera (Model eXcope K6; DIXI Science, Daejeon, Korea). Scanning electron microscopy was carried out with the SEM (Model SNE-3200M; SEC Co., Suwon, Korea).

RESULTS

Systematic overview

Table 1 presents a summary of species at different sites in 2015–2016.

Phylum Bryozoa Ehrenberg, 1831
Class Gymnolaemata Allman, 1856
Order Ctenostomata (or Ctenostomatida) Busk, 1852
Family Hislopiidae Jullien, 1885
Genus *Hislopia* Carter, 1858

¹*1. *Hislopia proluxa* Hirose and Mawatari, 2011

Norodonia cambodgiensis: Jullien, 1880: 78.
Norodonia sinensis: Jullien, 1880: 79.
Hislopia malayensis: Anandale, 1916: 35–37; Wood et al., 2006: 106, 108.
Hislopia lacustris: Anandale, 1911: 202–205.
Hislopia cambodgiensis: d'Hondt, 1983: 19, 21; Hirose and Mawatari, 2007: 636–638.

Hislopia sinsensis: d'Hondt, 1983: 19, 21.

Hislopia proluxa: Hirose and Mawatari, 2011: 19–25.

Material examined. Geum River (G2): Rocks close to a stone bridge crossing the river; Chopung reservoir (G1): drifting material such as plastic bottles (Fig. 2A). Sampling took place in early August which is reflected by high water temperatures, such as 30.7°C on 2 Aug in the Chopung Reservoir.

Description. Colonies abundant on both sites. Zooaria forming a flat, more or less solid layer closely attached to substratum, sheet-like, or in uniserial runners (Figs. 2B–D, 3A). Ectocyst transparent (Chopung reservoir) or slightly yellowish-brown (Geum River). Majority of zooids, broad-elliptical, flattened and often with narrow pedicles at their extremities (Figs. 2D, 3B, C). Zooids large in comparison to several other *Hislopia* species: average length, 1,109.01 µm; average width, 518.89 µm; average L/W ratio, 2.3 (N = 18) (Table 2). No spines around orifice, lophophore bearing 16–19 tentacles (15 countings) (Fig. 2E). Bud narrow elongate cylinder, and nearly reaching its full length before expanding at distal end (Fig. 2F). Second type of zooids elongate, tubular and resembling zooids of *Paludicella*. Forming uniserial chains, barely attached to substratum (Fig. 2G, H).

Distribution. *Hislopia proluxa* has only been described for several localities on the main island Honshu in Japan.

Remarks. The genus *Hislopia* Carter, 1858 occurs over a great part of Asia (Anandale, 1916) and consists of nine species. In four of them [*H. corderoi* Mane-Garzon, 1960, *H. lacustris* Carter, 1858, *H. lacustris moniliformis* Anandale, 1911 and *H. placoides* (Korotnev, 1901)] the orifice is armed with spines; in *H. lacustris moniliformis* and *H. placoides*

Korean name: ¹*긴히슬롭이끼벌레

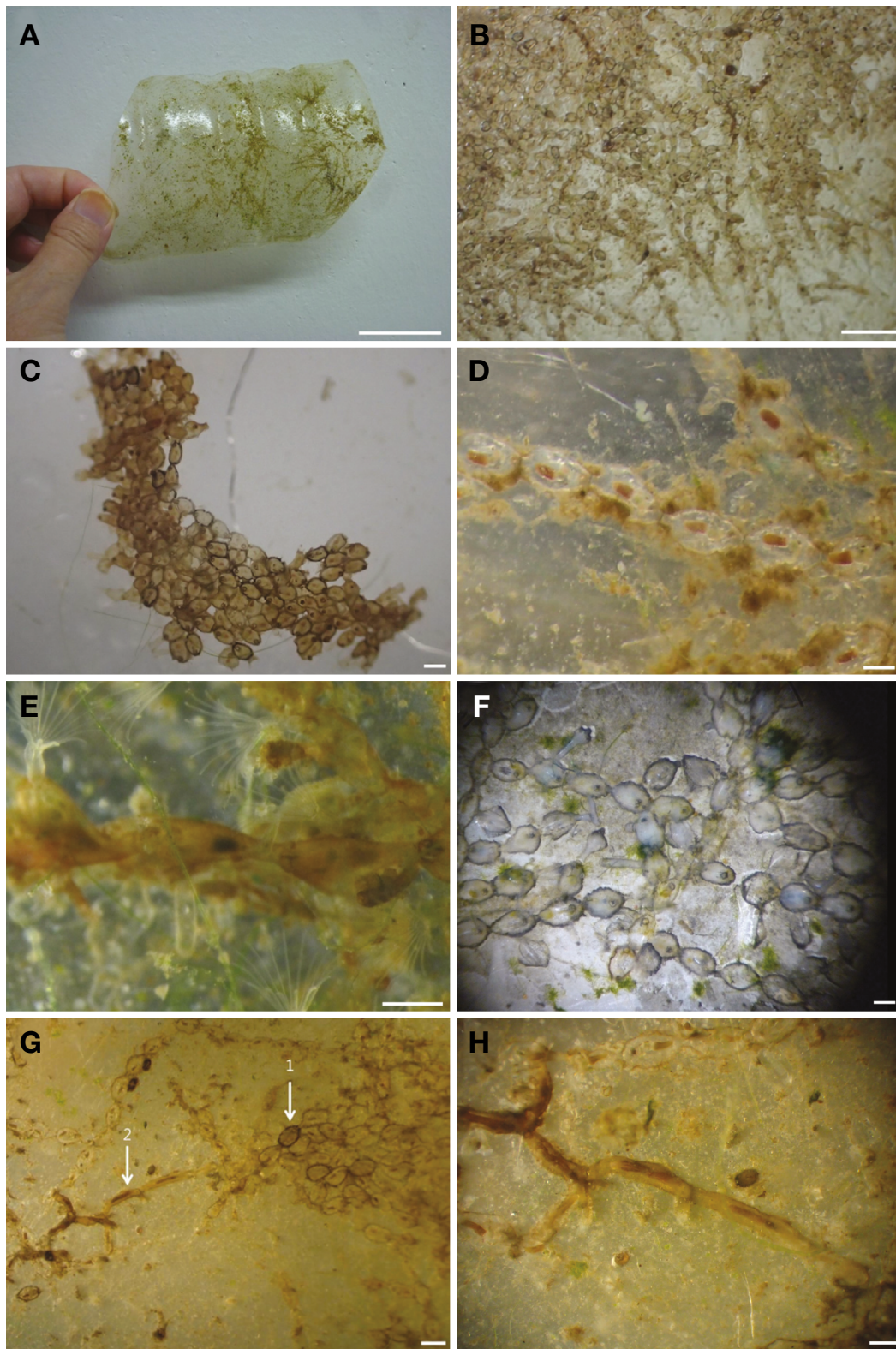


Fig. 2. *Histoplia prolixa*. A, Colony on plastic substrate; B, Colony details of 2A; C, Multiserial encrusting part of colony; D, Uniserial encrusting part of colony. Broad-elliptical zooids; at the extremities narrow pedicules; E, Zooids; F, Budding: elongate cylinders reach their full length before expanding at the distal end; G, Two types of zooids: 1, broad-elliptical; 2, elongate; H, Elongate type of zooid. Scale bars: A=3 cm, B=2 cm, C=1 mm, D, F, H=500 µm, E=800 µm, G=1,000 µm.

Table 2. *Hislopia prolixa* zooids: measurement of length (μm), width (μm), and L/W-ratio

Zooid number	L	W	L/W
1	935.49	416.25	2.25
2	1,187.36	492.13	2.41
3	803.79	438.85	1.83
4	864.98	481.28	1.79
5	911.17	528.57	1.72
6	1,044.37	638.69	1.63
7	1,041.07	573.08	1.82
8	990.12	454.81	2.18
9	1,055.46	586.69	1.80
10	879.55	599.28	1.47
11	981.58	556.63	1.76
12	1,151.59	632.95	1.82
13	906.21	624.86	1.45
14	993.33	565.14	1.76
15	950.83	440.53	2.19
16	883.00	598.56	1.48
17	1,429.20	334.57	4.27
18	2,953.21	377.26	7.82
Range	803.79–2,953.21	334.57–638.69	1.45–7.82
Average	1,109.01	518.89	2.3

the zooids are clearly smaller, and in all but *H. malayensis* Annandale, 1916 budding significantly differs from the budding types of *Hislopia prolixa*. In those budding types the buds grow as a narrow cylinder that reaches its full length before expanding at a point other than the distal end or the buds grow as a cylinder but start expanding before they reach their full length (Hirose and Mawatari, 2011). The significant difference from *H. malayensis* is the occurrence of a second elongate type of zooecium which is in our samples completely recumbent while Hirose and Mawatari (2011) describe this second type of zooid as “weakly attached to or completely erect from the substratum.”

Family Paludicellidae Allman, 1885

Genus *Paludicella* Kraepelin, 1887

¹**2. *Paludicella articulata* (Ehrenberg, 1831)**

Paludicella articulata: Toriumi, 1941: 414–415; 1952: 258–259; d’Hondt, 1983: 41; Hayward, 1985: 74–76; Wood, 1989: 55–58; Wood and Okamura, 2005: 43, 73; Hirose and Mawatari, 2011: 25–26.

Paludicella pentagonalis: Annandale, 1916: 30–31; d’Hondt, 1983: 41.

Paludicella elongata: Annandale, 1916: 29.

Material examined. Found at the bank of the large Han River (H1) on branches and in the Andeok water reservoir (G3) on rope. Colonies were sampled in very shallow parts of the Han river bank, where water temperature reached 28.9°C on 3 Aug.

Description. Colonies either recumbent or adherent, but very often erect and frequently vertically rising from substrate. Zooaria consisting of monoserial chains of autozoecia, every zoecium attached to previous one only in its proximal zone (d’Hondt, 1983). Occasionally forming lateral branches, either singly or in opposite pairs (Wood, 1989). ctocyst rather thick, yellowish-brown, seldom transparent as in samples of H1 (Fig. 4) and without incrustations. Zooids tubular, slender, spindle-shaped.

Distribution. *Paludicella articulata* is widespread and has been reported in most zoogeographic regions, except for the Afrotropical and the Pacific Oceanic Islands (Massard and Geimer, 2008a, 2008b).

Remarks. The genus *Paludicella* comprises only two species: in *P. pentagonalis* Annandale, 1916 the orifice is distinctly pentagonal (Annandale, 1916), while in *P. articulata* it is quadrangular (Fig. 4). *Paludicella articulata* is often found together with phylactolaemate species (Wöss, 1994). D’Hondt (1983) states that the variability of specimens in size and proportions of the various parts of the zooecia is very high and Toriumi (1952) describes different zooid shapes, densities and branching modi and gives ten-

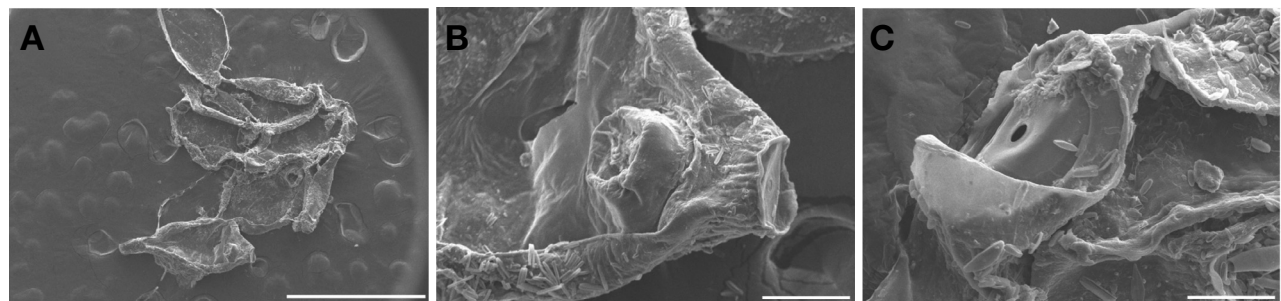


Fig. 3. *Hislopia prolixa*. A, Colony with broad-elliptical zooids; B, Zooid ends in a pedicle with horny plate; orifice subterminal, supported on a circular neck, no spines; C, Terminal part of the zooid: plate with pore. Scale bars: A=1 mm, B=100 μm, C=50 μm.

Korean name: ¹*마디민물이끼벌레

tacle number from 15–18. *Paludicella articulata* was the only gymnolaemate taxa that had been recorded before in South Korea (Toriumi, 1941). He collected the species in Bukeiko (unknown site), Hamgyeongbuk-do and Yeosu, Jeollanam-do. Unfortunately, this information is not precise enough for a revisit of his sampling places.

Family Victorellidae, Hincks, 1880

Genus *Victorella* Braem, 1951

¹*3. *Victorella pavid* Saville Kent, 1870

Victorella pavid: Kent, 1870: 34–39, pl. IV; d’Hondt, 1983: 51–54; Hayward, 1985: 96–99; Wood and Okamura, 2005: 43, 72; Wood et al., 2006: 110–113.

Victorella bengalensis: Annandale, 1911: 195–198; 1916: 32–33.

Material examined. Colonies were found on submerged macrophytes and branches in the Hyangho (K1) and Sunfo Wetlands (K2). Wetlands K1 and K2 of Gangwon-do represent brackish environments. K1 is practically adjacent to the East Sea and the high values for salinity and conductivity demonstrate the marine influence. In K2, a pond in vicinity to of rice fields, salinity as well as conductivity is comparatively very low (Table 3).

Description. Colonies numerous and showing luxurious growth (Fig. 4B). Completely covering parts of stems and leaves of submerged macrophytes and helophytes. Zooar-

ia consisting of erect or semi-erect tubes joined together at base in narrow encrusting portions similar to stolon. Zooids dense and erect. Ectocyst yellowish and only slightly transparent. Lophophore small and bearing exactly 8 tentacles (Fig. 4C).

Distribution. *Victorella pavid* is cosmopolitan (d’Hondt, 1983; Massard and Geimer, 2008a, 2008b) with a preference for brackish water. It can occur within a wide range of salinities (Carrada and Sacchi, 1964), such as in Gangwon Province, including entirely freshwater habitats (Hayward, 1985). It is also known to exist in the littoral zone of the sea (Annandale, 1911).

Remarks. The zooecia, when young, resemble those of *Paludicella*. Later the terminal upturned parts increase more rapidly while the basal parts remain completely attached to the substratum and appear as a mere swelling. The vertical parts contain a very long tubular peristome with the polypide (d’Hondt, 1983). Annandale (1911) also stated that the arrangement of erect tubules (the peristome) joined together in a cruciform manner at the base is complicated by adventitious buds and tubules round the terminal region of the zooecia. Wood et al. (2010) indicated that colony form depends on zooid density and possibly other factors. In any case, the constant number of tentacles serves as diagnostic character.

At present the genus *Victorella* comprises five species (Bock, 2016), as *V. bengalensis* Annandale, 1908 which has also been reported from South-East Asia (Annandale, 1911)

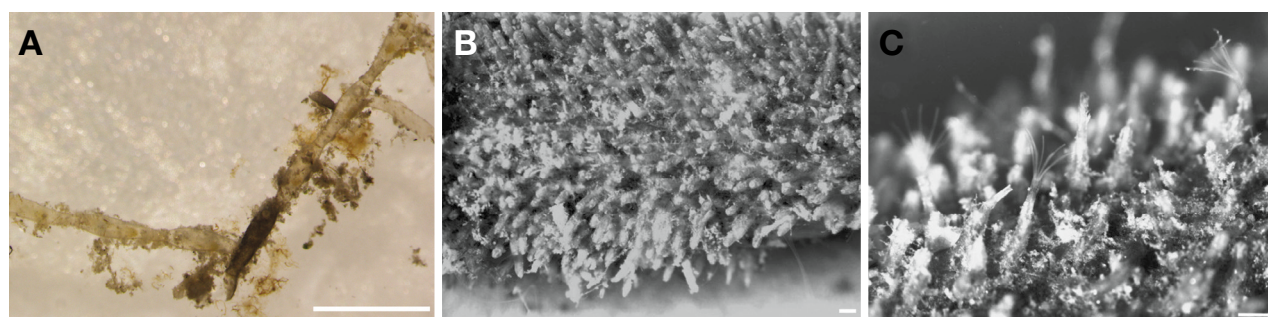


Fig. 4. A, *Paludicella articulata*. monoserial chains of autozooids. B, C, *Victorella pavid*. B, Colony; C, Zooids: lophophore with exactly 8 tentacles. Scale bars: A=1 mm, B, C=500 µm.

Table 3. Environmental parameters of K1 (Hyangho wetland) and K2 (Sunfo wetland)

Site	Date	Temperature (°C)	Conductivity (µS/cm)	Salinity (ppt)	Dissolved oxygen (%)	Dissolved oxygen (mg/L)	pH
K1	17 Aug 2016	31.3	14,878	8.56	69.60	4.9	8.3
K2	18 Aug 2016	29.4	3,111	1.61	35.5	2.69	7.3

Korean name: ¹*한들한들빅토리아이끼벌레

is not valid any more. As d'Hondt (1983) and Wood et al. (2006) indicated, *V. bengalensis* can be considered as synonym of *V. pavida*.

DISCUSSION

South Korea has currently on record three gymnolaemate freshwater bryozoan species which is nearly as many as in the whole of Europe (Fauna Europea: 4 Ctenostomata; Wöss, 2013).

When sampling takes place, gymnolaemate taxa are sometimes not easily detected, as their zooids are smaller in comparison to phylactolaemate species. Furthermore, in the case of the Gymnolaemata, it is essential to investigate growth pattern and morphological details of the colonies and zooids when they are alive, as diagnostic characters of the species are marginally bound to resting stages as in the case of the Phylactolaemata. The majority of freshwater bryozoans in South Korea are assigned to the class Phylactolaemata, however, as seen in this study, the abundant growth of *Hislopia prolixa* and *Victorella pavida* on various substrate indicates that they are a considerable factor in some benthic freshwater communities. *Paludicella articulata* has been on record in South Korea since it was reported more than seventy years ago. All three genera are represented in Southeast Asia and the question remains, how colonization of these bodies of water took place. Regarding this point, in the case of the Phylactolaemata, the extraordinarily important role of the resting stages, the different kind of statoblasts, has to be emphasized. Especially, as floatoblasts-drifting in the water with the help of a swimming-are predestined to colonize new habitats and spinoblasts-possessing hooks and spines-can attach to large organisms, e.g., to the feathers of migrating waterfowl. As the resting stages of the Gymnolaemata, the hibernaculæ, are adherent to the substrata, strategies of dispersal must differ. They could be transported as part of whole substrates, such as with a plastic bottle covered with colonies (see site G1) (Fig. 2A). Alternatively, only fragments of colonies need to be considered as units of transportation. Colonies with erect growth form, such as *P. articulata*, actually can undergo fragmentation and parts of colonies serve as propagules (Wiebach, 1954; Wöss, 2005). It is to expect that gymnolaemate species occur in a wide range of water bodies in South Korea and further research is definitely needed to estimate their distribution patterns.

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